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SIMULATED MSG SEVIRI IMAGERY FROM THE HARMONIE-AROME HIGH-RESOLUTION NUMERICAL WEATHER PREDICTION MODEL: APPLICATIONS IN AEMET

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Abstract

Simulated Satellite Imagery (SSI), generated by applying a radiative transfer (RT) model to atmospheric profiles from Numerical Weather Prediction (NWP) model output, has become increasingly realistic during the last decade, as a result of advances in both NWP and RT modeling. In particular, current high-resolution mesoscale NWP models have nominal horizontal resolutions in the same range as geostationary imagery.

SSI has a wide range of applications, of which perhaps the best known is as proxy for new platform-sensor. Another application area of SSI is operational weather forecasting: 1) simulated images can be used as snapshots of the atmospheric state represented by an NWP forecast, and 2) the comparison between observed images and simulated images from an NWP analysis or a very short-range forecast can help make an overall assessment of the initial conditions of that forecast. Another application of SSI is NWP model development and validation: the comparison of simulated and observed imagery can help assess the ability of a specific NWP model-version to represent atmospheric processes.

This contribution presents work in progress in AEMET (Spanish Meteorological Institute), within the HIRLAM (HIgh Resolution Limited Area Model) European consortium, with simulated SEVIRI imagery from the HARMONIE-AROME mesoscale model and the RT model RTTOV (Radiative Transfer for TOVS), to explore and develop applications of SSI, focusing on the comparison between simulated and observed imagery in the areas of operational forecasting and NWP model validation. SEVIRI (Spinning Enhanced Visible and Infrared Imager) is the main payload of the Meteosat Second Generation (MSG) geostationary satellites, and this work focuses on SEVIRI channels IR10.8 and WV6.2.

BACKGROUND AND MOTIVATION

Satellite imagery simulated from NWP model output, using fast RT models has become considerably more realistic during the last decade, as a result of advances in both NWP and RT modelling. Current NWP mesoscale models are typically non-hydrostatic convection permitting, and the nominal horizontal resolution, i.e. the distance between grid points, is in the same range as the horizontal resolution of current geostationary satellite imagery. For instance, for its default configuration, the HARMONIE-AROME high-resolution model (Seity et al., 2011; Bengtsson et al., 2017) has a horizontal resolution of 2.5 km, while the horizontal resolution of SEVIRI images is 3 km at the sub-satellite point for all the bands except HRVIS. The current version of the fast RT model RTTOV allows to estimate radiances or brightness temperatures (BT) from NWP model profiles for a wide range of instruments, and in particular for the 12 spectral bands of SEVIRI on the MSG satellites.

In order to assess the quality of NWP forecasts, one of the keys is the comparison with suitable observations. However, if the variables observed are not prognostic variables, the comparison is meaningful only if it is possible to generate, from the analyzed or forecast model state, a good simulation of the variable observed, i.e. a good model-equivalent of the observation. In addition, the comparison between a pair of simulated images (e.g. from a forecast and the corresponding analysis) may also provide valuable information. Simulated satellite images, formed by presenting simulated BTs either at the grid points of an NWP domain (i.e. using the model native geometry) or at the pixels of a specific satellite-instrument (i.e. using the satellite geometry) open ways of evaluating NWP products through image comparison.

The current level of realism of SSI paves the way to extend its use beyond well-established applications, such as a proxy for new platform-instrument imagery, and consider applications such as the evaluation of NWP forecasts. In recent years there has been a growing interest in the comparison between observed and simulated imagery to assess the accuracy of NWP cloud forecasts, including the metrics to carry out such comparisons (Griffin et al., 2017a; Griffin et al., 2017b).

This contribution presents the work in progress in the NWP group of AEMET to develop a framework for the operational generation of SSI from the HARMONIE-AROME high-resolution model, and to explore applications in the areas of operational forecasting and NWP model evaluation.

SIMULATED MSG SEVIRI IMAGERY FROM HARMONIE-AROME

HARMONIE-AROME is a non-hydrostatic convection-permitting NWP limited-area model (LAM), used widely in the HIRLAM community for their mesoscale short-range NWP, both operationally and in research mode. Figure 1 shows simulated images produced with HALSSI (HARMONIE-AROME LAM SSI), an application that generates SSI from HARMONIE-AROME analyses and forecasts using the fast radiative model RTTOV, and that is currently in development in the NWP group of AEMET, within the HIRLAM group.

RTTOV is a very fast RT model, developed by the EUMETSAT NWP SAF (Saunders et al., 2018), that allows to simulate the top of the atmosphere (ToA) radiances that a sensor would measure for a given atmospheric profile, surface conditions and satellite viewing geometry. RTTOV supports a wide range of satellites and sensors, and in particular all SEVIRI channels on Meteosat-11, the MSG satellite that currently provides the 0 degree longitude service. HALSSI uses RTTOV version 12.

The images shown in Fig. 1 have been produced from the output of an NWP experiment with settings very similar to those in the operational runs of HARMONIE-AROME in AEMET, including the domain, with a Lambert Conformal projection and a nominal horizontal resolution of 2.5 km, and the version (cycle 40h1.1). There are 65 vertical hybrid levels, with the model top at 10 hPa and the lowest level at 12 m. Boundary conditions are taken from the ECMWF HRES (High Resolution) model. In this example, BTs for SEVIRI channels IR10.8 and WV6.2 on Meteosat-11 have been simulated for each grid point in the domain, and the images consist of BTs on grid points, i.e. their geometry is model-native.

Regarding global SSI, The ECMWF generates routinely simulated images from its operational HRES 10-day forecast. Since March 2016 these simulated images are global, with model-native geometry: simulated BTs are produced for each grid point, as if the satellite was located just above it, for SEVIRI channels IR10.8, WV6.2 and WV7.3 on Meteosat-10. The reader is referred to the ECMWF web site for details (https://confluence.ecmwf.int/display/FCST/Simulated+satellite+data). Figure 2 shows an example of such images, for the same time and a region covering the domain of the images shown in Fig. 1.

SSI generated from HARMONIE-AROME and ECMWF HRES has a complementary role. While HARMONIE-AROME has a higher nominal horizontal resolution (and therefore a more accurate representation of the orography), and can represent deep convection explicitly, ECMWF HRES is global and its range is considerably longer. As is the case with LAM and global NWP, HARMONIE-AROME SSI gives more details than ECMWF HRES SSI in a small geographical area of interest.

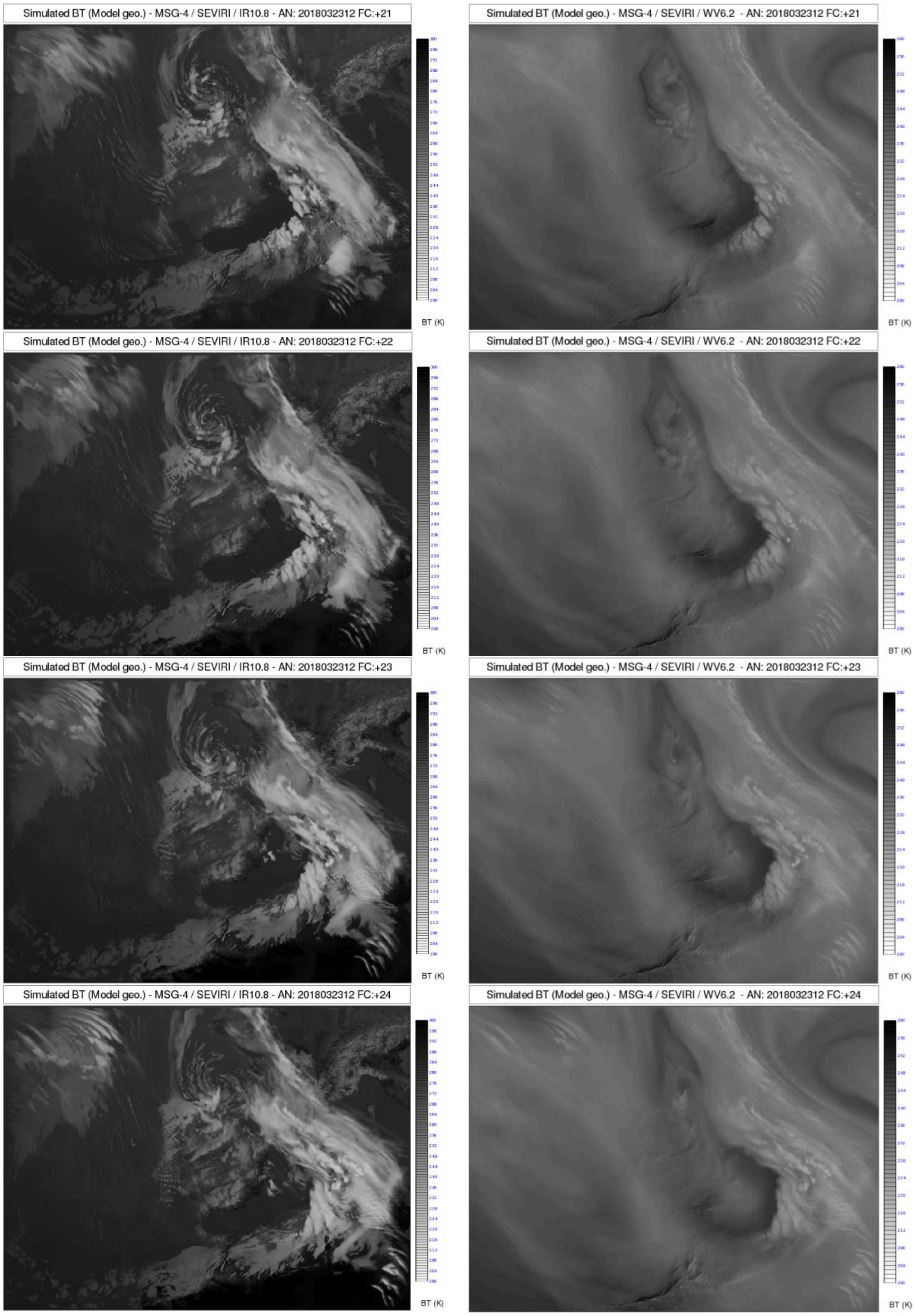

***Figure 1*: Sequence of hourly SSI from HARMONIE-AROME during cyclone Hugo: from AN 20180323 at 12 UTC, FC HH+21 to HH+24 from top to bottom. SEVIRI channel IR10.8 on the left, and WV6.2 on the right.**

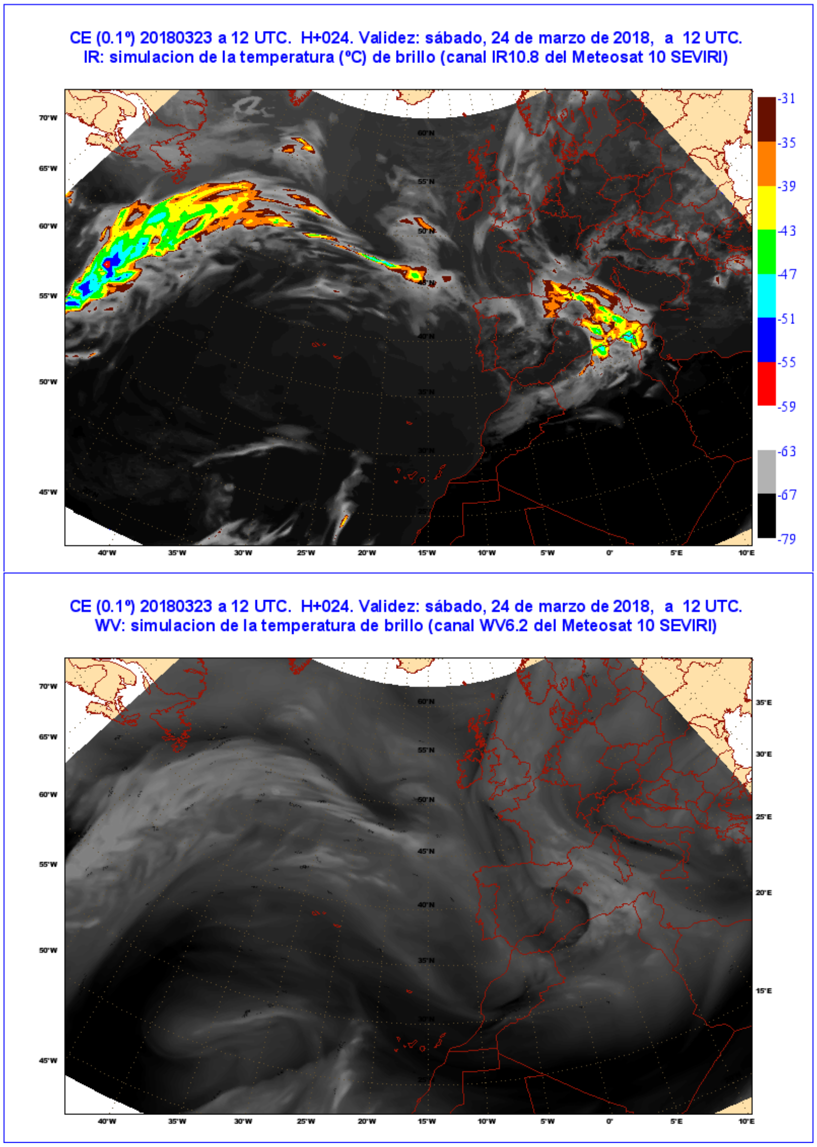

***Figure 2*: SSI from ECMWF HRES model during cyclone Hugo: FC HH+24 from AN 20180323 at 12 UTC. Top: SEVIRI channel IR10.8, bottom: WV6.2.**

APPLICATIONS

There is a number of applications of SSI, including as proxy for future platform-sensor, in operational forecasting, or for AMV (Atmospheric Motion Vector) studies. Thanks to the increasing realism of SSI, the range of applications is becoming wider. In the work described here we focus on two areas: operational weather forecasting, and NWP model development. SSI from models such as HARMONIE-AROME, with a high horizontal resolution and explicit representation of deep convection, can be particularly useful in case studies in both areas.

Applications in Operational Weather Forecasting

In operational weather forecasting, simulated images can be used to summarize an NWP analysis or forecast, in an intuitive way, as shown in Fig. 1. As with observed SEVIRI imagery, IR10.8 images provide a snapshot of cloud systems, and WV6.2 images give a snapshot of the dynamics of the middle and upper troposphere. Figure 3 illustrates the value of WV imagery in operational forecasting. SSI from the ECMWF HRES model have been used routinely for more than one decade in operational forecasting in AEMET.

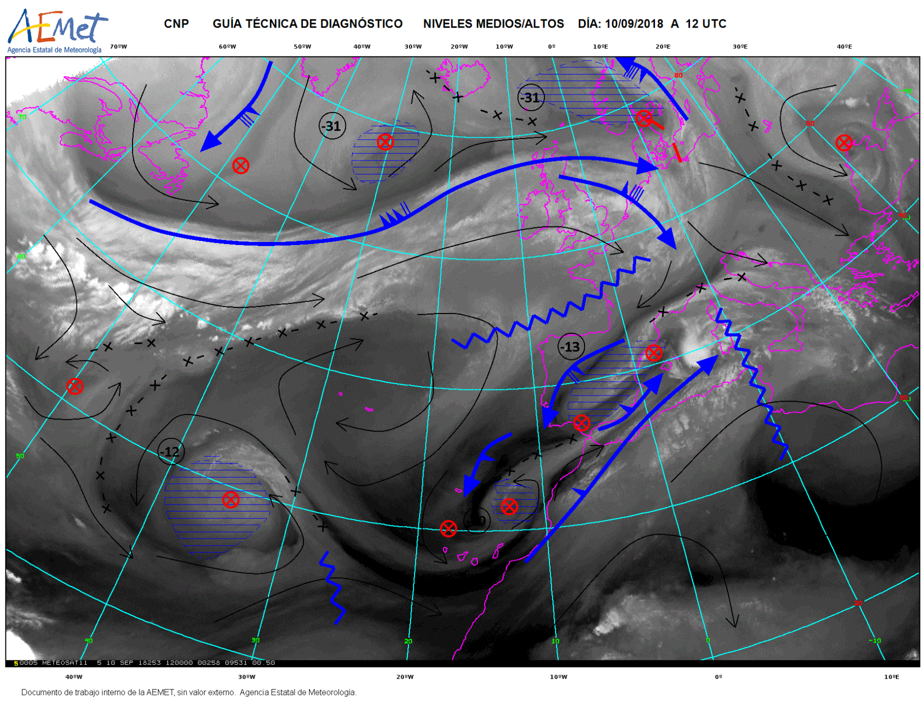

***Figure 3*: Sketch emphasizing the main features of the upper and middle tropospheric flow, using an observed Meteosat-11 WV6.2 image as one of the key fields. Source: Centro Nacional de Prediccion, AEMET.**

The presentation of an NWP forecast as simulated imagery may also contribute to a seamless transition from nowcasting to short-range NWP, by providing a bridge between observed satellite imagery and NWP model output.

SSI can also help assess the quality of the initial conditions of NWP forecasts. By the time the analysis and forecasts from an NWP run reach the operational forecasting room, observed images for the analysis time (and for some very short-range forecasts) are already available. The comparison between SSI and their counterparts in observed imagery allows to assess quickly how well the characteristics of the key features are represented in the analysis and very short range forecasts. If simulated and observed images share the geometry, the difference image can be particularly useful (shown e.g. in Hernandez and Hortal, 2014).

Applications in NWP model development

SSI is valuable tool in model development: it can be used in case studies, to compare different versions of a model (see Figure 4) or different options for the same model and version, e.g. different parameterizations of a physical process.

The degree of realism of current SSI allow to be optimistic about the uses of SSI for model evaluation based on objective comparison between simulated and observed imagery. However, for any type of application that needs like-to-like comparisons, the simulated images need to mimic not only the channel, sensor and platform, but also the satellite geometry and perspective. BTs need to be simulated at the locations of the pixels in the observed imagery, for realistic satellite zenith and azimuth angles, and possibly also taking into account the slanted view for large satellite zenith angles.

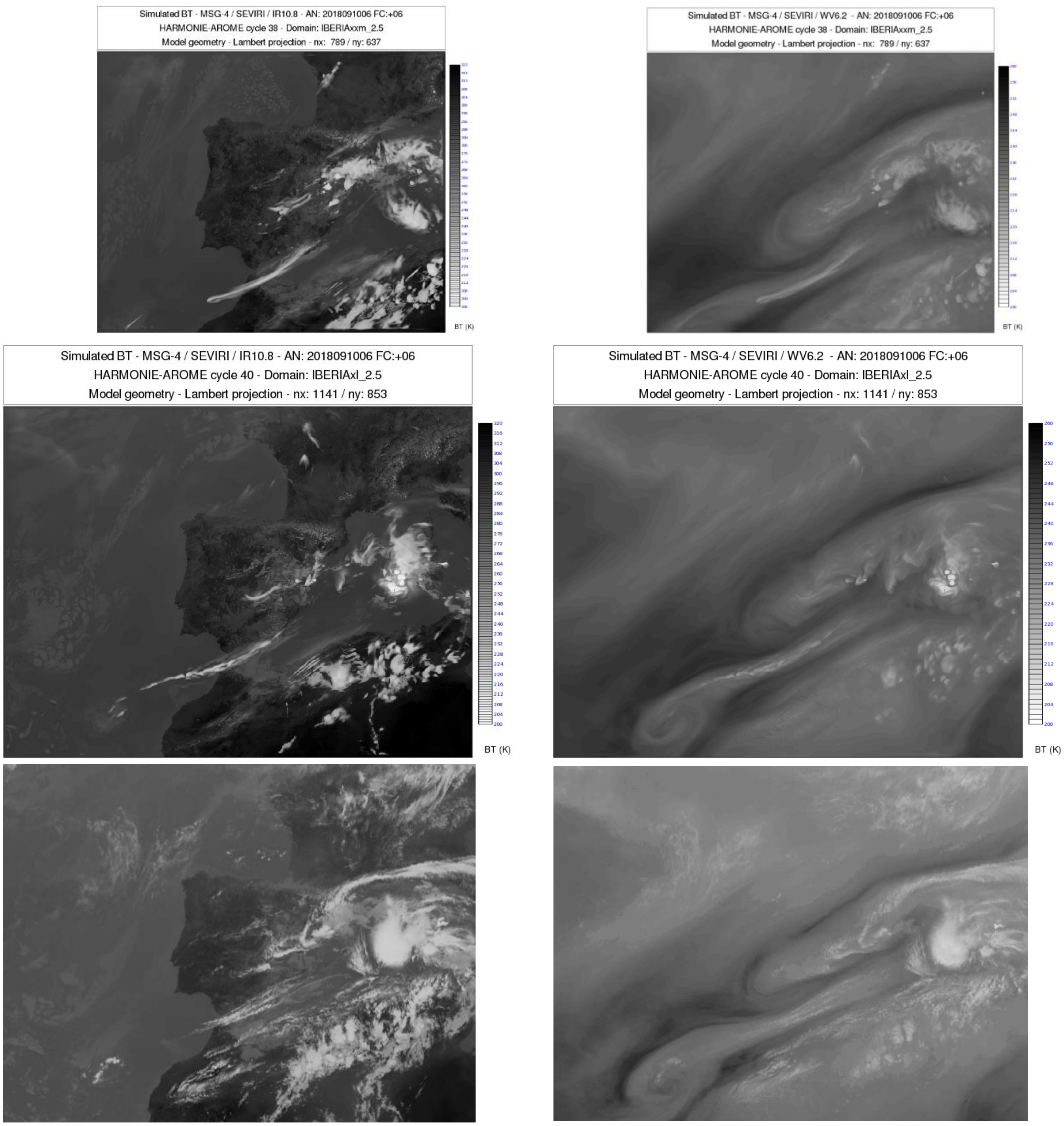

Figure 4**: IR10.8 (left) ad WV6.2 (right) images from an experiment based on cycle 38 of HARMONIE-AROME (top), from an experiment based on cycle 40 (middle) and observed Meteosat-11 (bottom), all for 20180910 at 12 UTC.**

Figure 5 shows a pair of SSI, adapted to satellite geometry. Simulated BTs at pixel locations have been calculated from BTs simulated at model grid points, following a nearest grid point approach. However, other alternatives are possible, and perhaps desirable for some applications. The obvious options are (depending on the NWP grid and satellite horizontal resolutions) interpolation or weighted average. While interpolation tends to produce artificially smooth images, the nearest neighbour approach tends to create artificial steps. It seems likely that the best choice depends on the application and on the relative satellite-grid horizontal resolution, which in some cases varies for the same satellite-sensor from one geographical region to another.

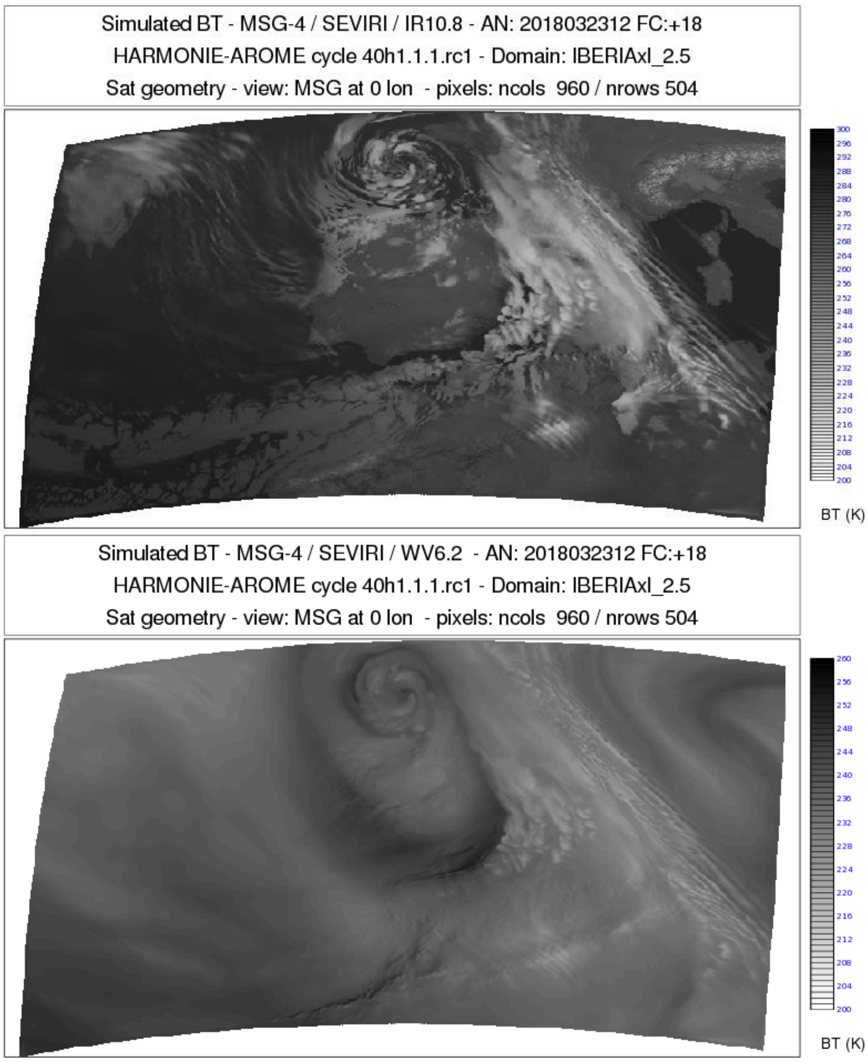

***Figure 5*: IR10.8 (left) and WV6.2(right) SSI from the same sequence as in Fig.1, re-mapped to satellite geometry (MSG at 0 degrees longitude).**

OUTLOOK

Our recent work has focused on the development of HALSSI, driven by the needs that the exploration of possible applications has brought to the surface. Discussions between different groups, including NWP development and operational forecasting, have helped to understand the different perspectives, needs and strengths.

Plans for the near future include: 1) the release of HALSSI within the HIRLAM consortium, and the extension of its functionality, according to requests and resources, and 2) the exploration and development of methods to evaluate NWP analyses and forecasts by objective comparison between simulated and observed MSG imagery.

Regarding model evaluation by objective image comparison, it is important to remember that the generation of SSI from model output is the result not only of the NWP model and the RT model, but also of how the RT model is used, and how the simulated radiances are mapped to pixel locations. It would be naïve to relate the differences between simulated and observed radiances to the NWP model only. This is an area in development, where experience is limited. Considering the following questions will, in our view, stimulate progress in sound directions:

- What kind of features does it make sense to compare between simulated and observed satellite imagery?
- How to characterize e.g. statistically or geometrically these features, in such a way that the comparison is meaningful and feasible in practice?
- How to summarize and present objective comparisons for the purpose of NWP model evaluation?

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